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Dairy cow longevity and farm economic performance: Evidence from Swedish dairy farms

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ABSTRACT

The longevity of dairy cows is mainly determined by farmers' subjective culling decisions and can be linked to the environmental impact of dairy production and to the social acceptance of the industry. Still, the economic impacts of dairy cow longevity are not well understood. The aim of this study was to examine how herd average dairy cow longevity is related to the farm economic outcome. We used 3 indicators of economic outcome: technical efficiency, profitability, and average milk yield per cow. We used 2 indicators of dairy cow longevity: average herd length of life and average herd length of productive life. The study was based on a unique and detailed dataset from Swedish dairy agriculture, where herd-management data from the national dairy herd recording scheme were combined with farm-level economic variables from the Swedish Farm Accountancy Survey, for a total of 1,959 observations from 2010 to 2018. The regression results highlight that both measures of average herd dairy cow longevity have an overall positive and significant association with farm-level economic performance. These associations had an inverted U-shape, which implies that the association is first positive and then declines. Descriptive statistics indicate that the point where the maximum economic performance is attained varied across the economic indicators. Our results are relevant for individual dairy farmers and their advisors, who are interested in understanding how herd average longevity relates to economic performance on the farms. Our results are also important from a greater sustainability perspective, because linking them to previous knowledge about the environmental and social sustainability benefits of keeping cows longer highlights longevity-associated trade-offs between those benefits and the farm economic outcomes.

Key words: economic performance, longevity, milk yield, productive life

INTRODUCTION

It is well established that current food production and consumption are not environmentally sustainable globally (Willett et al., 2019) or locally in Nordic countries (Wood et al., 2019), which are represented in the empirical focus of this paper. Combined with this is an increasing societal concern for the social sustainability of production, regarding how animals used for food production are kept and managed (e.g., McCarthy et al., 2004; Ingenbleek and Immink, 2011; Thorslund et al., 2017). Dairy cow longevity represents the length of life a dairy cow has in the herd (Grandl et al., 2019; Schuster et al., 2020). As such, it is a central aspect in the transition toward more environmentally sustainable and socially acceptable dairy production. Cows kept in production for a longer period of time have an environmental benefit because the effect of raising a heifer from calf to first calving is distributed over a potentially longer time of total milk production. In addition, increased longevity has been associated with less methane per kilogram of milk (Grandl et al., 2016, 2019). Keeping healthy cows in production for longer periods of time can also help increase the social acceptability of the production; culling of young dairy cows signals that the animals are kept in such a way that they cannot function in production over a longer period of time (Barkema et al., 2015; Röcklinsberg et al., 2016). Schuster et al. (2020) found that increased longevity is associated with good animal welfare, indicating older cows also can live a good life.

In farms where the dairy cows are generally in good health, cow longevity is mainly determined by farmers' subjective culling decisions that are driven by different factors. Culling, defined as the process of removing a cow from the herd, happens for a variety of reasons, including low productivity, low fertility, injuries and reduced health, and farmers' investment decisions (Gröhn et al.,

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2003; De Vries and Marcondes, 2020; Owusu-Sekyere et al., 2023). However, culling is also an economic decision, which is distinguished between involuntary and voluntary culling (Fetrow et al., 2006; Schuster et al., 2020). Involuntary culling targets cows with no possible productive future, whereas voluntary culling is done when the farmer decides it is economically sensible to cull (Fetrow et al., 2006) or when a surplus of replacement heifers calls for the removing of cows from the herd to make room for the next generation (Bergeå et al., 2016; Overton and Dhuyvetter, 2020). To guide farmers' decisions on culling and longevity of dairy cows, it is important that the associations between longevity and farm economic outcomes are well understood. From an economic perspective, short longevity can be associated with high herd replacement costs, which lead to higher costs of production or rearing costs (Heikkilä et al., 2008; Mohd Nor et al., 2012). In addition, short longevity cuts the productive and profitable life phase short, which has been found to increase with the number of lactations per cow in analyses of data from different countries with high-producing dairy cows, due to the high cost associated with early life (Boulton et al., 2017; Dallago et al., 2021). Still, it is not sufficiently well understood how the economic situation at the farm develops with the herd longevity. More knowledge in this area is important for understanding farmers' incentives to take actions to enhance dairy cow longevity to move more in line with environmental and social sustainability goals and is useful in advisors' guidance to dairy farmers. Also, the previous research does not include any country with similarly restrictive use of antibiotics as that of Sweden. This is a contextual difference that may affect decisions on the farm level when evaluating the risk associated with keeping higher parity cows in the herd (Bergeå et al., 2016).

Accordingly, this study aims to examine how herd average dairy cow longevity relates to the farm economic outcome. We use 3 indicators of economic outcome: (1) technical efficiency, which focuses on the ability of the farms to transform their production factors to output; (2) profitability measured by gross margin, defined as the total revenue minus the variable cost; and (3) productivity, which refers to the average milk yield per cow. These indicators give us the opportunity to highlight the relationship of dairy cow longevity with 3 central economic aspects of dairy production. The study is based on detailed and unique economic and animal management data obtained from a sample of dairy farms in Sweden. We merged the dairy farm economic survey data from the Swedish Farm Accountancy Survey (**FAS**) with data from the national dairy herd recording scheme (**NDHRS**) over the years 2010 to 2018. Despite the broad definition of longevity provided earlier, the literature provides different definitions and ways to measure longevity. Still, 2 measures are widely used in the academic discussions and on-farm application: the length of life (duration from birth until culling), and the length of productive life (duration from first calving until culling; Schuster et al., 2020; Dallago et al., 2021; Vredenberg et al., 2021). The longevity measures in the data are available at herd level and hence, our unit of analysis is dairy herds in Sweden.

MATERIALS AND METHODS

Background: Longevity in Swedish Dairy Cows

In Sweden, the empirical focus of this paper, dairy cows are on average kept in production for 2.6 lactations before being culled (Växa Sverige, 2021a). On average, 75% of the dairy cows reach their second lactation in Sweden, 50% reach their third and can move on to their fourth, and 30% reach their fourth lactation before being culled (NAV, 2008). The average age of first calving is 27 mo, which corresponds to an average herd life (from birth to culling) of about 60 mo (5 yr; Växa Sverige, 2021b). This is a short lifespan compared with the natural lifespan of dairy cows, which is approximately 20 yr (De Vries and Marcondes, 2020). The life period measure of longevity is lower in Sweden compared with both Canada and the Netherlands, which have similar high-producing dairy herds (Schuster et al., 2020). Moreover, despite a positive genetic trend for increased longevity of dairy cows, longevity in Sweden remained stable with no sign of change since 1990 (Bergeå et al., 2016; Alvåsen et al., 2018). Swedish dairy cows are high yielding (>10,600 kg ECM per cow and year) and considered healthy with an incidence rate of 20 veterinary-treated cows per 100 cows and year. The most common reasons for culling are udder health problems and low fertility (Växa Sverige, 2020, 2021b).

Data

Two data sources were used for this study: the FAS, which is the Swedish national data that contributes to the EU level Farm Accountancy Data Network (FADN) database, and the NDHRS from Växa. Both datasets contain data at a yearly level. The FAS dataset contains economic and production data for a sample of Swedish farms. The sample is stratified to be representative across farm type and geography, to be representative for Swedish agriculture. The FAS and FADN data are based on a rotating (unbalanced) panel that surveys an average of 1,000 farms every year, in which 10% of the samples are replaced every year. The FAS database was used in this study to construct variables to measure farm production inputs and outputs for the efficiency analysis, as well as data for the profitability analysis in this study. The NDHRS data include demographic information about the enrolled herds as well as data about production, fertility, health, and cullings in the herds. We construct variables of longevity measure and productivity (milk yield) from the database at the herd level; this means that the longevity measures reflect yearly herd average figures. The datasets were merged at the farm level. By merging these 2 databases we obtained a unique dataset to examine the relationships between yearly herd average dairy cow longevity and yearly farm-level efficiency, profitability, and productivity. In total, our dairy farm sample contains 1,959 observations spanning from 2010 to 2018.

For the efficiency analysis, our final data set summarizes production variables into 5 distinct production factors (variable cost, fixed cost, asset, labor, and land) and one output variable. Table 1 presents the summary statistics of these variables. The production factor variable specification used here repeats the specification used in Hansson et al. (2020) and Adamie and Hansson (2022), which both estimated efficiency of Swedish dairy production, and follows a standard production factor configuration in efficiency estimations (Coelli et al., 2005). The output variable specification merges the output considered in previous studies for Swedish dairy production (Hansson et al., 2020; Adamie and Hansson, 2022) to fit the model specification used in this paper. The variable costs include aggregates of specific costs and farming overheads, and the fixed cost captures costs incurred for depreciation, rent, and interest. The asset variable includes farm building, machinery and equipment, livestock, and working capital. The labor variable captures the total hours worked by both hired and nonhired labor, and land size accounts for the total land holding used at the farm, measured in hectares. The output variable includes cow milk and milk products, as well as beef and veal. Moreover, it also includes the output from other agricultural production and entrepreneurial activities. The total output is measured as total farm revenue in Swedish krona. The output (total farm revenue) and input (variable cost, fixed cost, and farm asset) variables are adjusted to 2015 constant prices.

To measure profitability and productivity, we used the gross margin (total revenue minus total variable cost) per year and the average milk yield (in ECM) per year, respectively. The cow longevity variables were productive life (herd average age at culling minus herd average age at first calving) and total lifespan (herd average age at culling). Beyond the main variables of interest, we used control variables, which included farm subsidy, herd size (number of milk-producing cows), milking system used, housing system, and breeds of dairy cows in the herd, to control for possible confounding effects (see Table 1 for details). Our sample consists of both conventional and organic farms; we opted to include both production types in the analysis, because previous research suggested that the differences between the 2 types in Sweden are not considerable (Höglind et al., 2021). Still, we control for the possible differences by including type of production as a control variable. The analysis was done at herd level.

Methods

This study used existing data from FAS and NDHRS. No animal subjects or sensitive personal data were used, so this analysis did not require approval from an Ethical Vetting Board according to Swedish research ethics legislation.

To achieve our objective to examine the relation between herd average dairy cow longevity and farm economic performance (measured by 3 indicators: farm technical efficiency, gross margin, and productivity), we implemented 2 approaches in our analysis: a technical efficiency analysis approach and a regression approach. The technical efficiency analysis approach estimates the technical efficiency of each dairy farm and links the resulting inefficiency to longevity measures, whereas the regression approach examines the association of longevity measures to profitability and productivity measures.

Technical Efficiency Analysis

We used a stochastic frontier approach using a translog specification of the production function (Equation 1) because of its flexibility (Christensen et al., 1973; Kumbhakar et al., 2014), to estimate farm-specific technical efficiency and to allow for a one-stage estimation of the efficiency model. The model was estimated using Stata (https://www.stata.com/).

$$lny_{it} = \alpha + \sum_{i}^{K}\beta_i lnx_{it} + \frac{1}{2}\sum_{i}^{K}\sum_{h}^{H}\beta_{ik} lnx_{it} lnx_h + v_{it} - u_{it}, \quad [1]$$

To accommodate technological change, the above production function is modified to account for time variable as follows:

$$lny_{it} = \alpha + \sum_{i}^{K}\beta_i lnx_{it} + \frac{1}{2}\sum_{i}^{K}\sum_{h}^{H}\beta_{ik} lnx_{it} lnx_h + \beta_t + \frac{1}{2}\beta_{tt}t^2 + \sum_{i}^{K}\beta_{it} lnx_i t + v_{it} - u_{it}, \quad [2]$$

Table 1. Descriptive statistics of variables at herd level used in the analysis

Variable[1]	Mean	SD	Minimum	Maximum
Production function variable				
Output (SEK)	4,150,000	2,807,011	545,405	1.74e+07
Variable cost (SEK)	3,563,585	4,226,998	277,292	5.53e+07
Fixed cost (SEK)	684,744	814,229	1,279	7,260,237
Assets (SEK)	1.14e+07	1.11e+07	209,900	1.39e+08
Labor (hours worked)	6,635	4,699	330	48,300
Land (ha)	164	154	15	1,673
Economic outcome variable				
Gross margin (SEK)	1,137,674	1,944,330	−1,373,121	2.61e+07
Milk yield (kg ECM)	9,641	1,533	3,121	14,264
Longevity variable				
Cow productive life (d)	1,028.0	238.8	384.5	2,930.7
Cow age at culling (d)	1,882.3	262.6	1,235.5	3,768.7
Other control variable				
Subsidy (SEK)	562,418	100	16,815	11,296,460
Calving interval (mo)	13.5	1.2	11.4	22.9
Number of cows	90.9	97.2	10.0	1,334.7
Milking system (3 categories)				
Automatic		29.9		
Milking parlor/rotary		22.8		
Tiestall		47.3		
Breed (4 categories)				
SR (≥80%)		21.2		
SH (≥80%)		24.5		
SR + SH (≥50%)		39.4		
Other breeds		15.0		
Type of barn (3 categories)				
Freestall, noninsulated		10.3		
Freestall, insulated		36.9		
Tiestall		52.8		
Production system (2 categories)				
Organic		16.0		
Conventional		84.0		
Number of observations		1,959		

[1]SEK = Swedish krona; SR = Swedish Red. SH = Swedish Holstein. Productive life = age of cow at culling (d) minus age at first calving. For milking system, breed, and barn type variables, the proportion of each category in the total sample is given. 1 US$ = approximately 11 SEK in 2023.

where y_{it} represents total farm specific output at time t, x_{it} represents the K inputs used in the production process (the production input variables in our case) and h represents other factors affecting production other than i and t is a time variable. The last 2 terms in the model specify the composite error term, where v_{it} is a 2-sided random noise component and u_{it} is the inefficiency component of the error term. It is worth mentioning that in Equation 2, we interacted the input variables with time (t) to account for heterogeneity over time (Cameron and Trivedi, 2010). The inefficiency distribution is modeled as half-normal.

To examine the effect of longevity variables on inefficiency, we implement the auxiliary model for the inefficiency effects defined as follows:

$$u_{it} = \beta + \beta_i Z_{it} + \varepsilon_{it}, \qquad [3]$$

where Z_{it} represents variables of interest, which includes the longevity variable and other control variables that are assumed to affect farm inefficiency. ε_{it} is the error term. The longevity variable includes herd average productive life (duration from first calving to culling) and age at culling. The other control variables include farm size (measured by number of cows), subsidy, farm type (organic or conventional), housing system, milking system, and breed. The estimation of the inefficiency scores and the efficiency effects model (i.e., Equations 2 and 3) are implemented in a one-stage approach. Still, it should be noted that the efficiency scores are estimated from the production function specified according to Equation 2, and considering how the farms can transform production factors into production outputs, and that the effects of the longevity variables on inefficiency are estimated from Equation 3, which specifies the considered determinants of inefficiency. It should also be noted that with our specification of time trends, we are able to model technological change over the considered time period, through the time variables specified in Equation 2 and time fixed effects in Equation 3 to account for time-specific efficiency effects.

To sum, the model specification used to estimate technical efficiency and how longevity variables and control variables relate to the technical inefficiency, follows a standard approach. The first part of the model represents the production function, where production output is modeled as a function of production factors. The second part is thus the inefficiency model, which explains the reasons for inefficiency as estimated in the first step. Here, the longevity variables are our main focus, but we also control for other factors that might explain inefficiency from the first part of the model.

Regression Analysis

To examine the relation between economic performance (as measured by the gross margin and milk productivity) and longevity, we implement a linear regression approach given by:

$$y_{it} = \alpha + \beta_1 l_{it} + \beta_2 l_{it}^2 + \gamma X_{it} + \varepsilon_{it}, \quad [4]$$

where y_{it} represents the economic performance variable (gross margin or milk productivity), l_{it} denotes the longevity measure included as level and squared value to accommodate for nonlinearity effect and X_{it} represents a vector of other control variables explained earlier and presented in Table 1. Given the small sample size over the sample period, we estimated an ordinary least squares (**OLS**) model on a pooled data, included time fixed effects, with robust standard errors clustered by farm. In addition, the data set contained variables that are constant across observations but which evolve over time, and as such with the inclusion of time (year) fixed effects, the OLS model yields efficient and consistent estimates. In this way, we eliminate omitted variable bias caused by excluding unobserved variables that evolve over time but are constant across entities.

RESULTS

Efficiency Analysis: Longevity and Efficiency Using Inefficiency Effects Model

The translog production function model from which we estimated the efficiency scores is presented in Table 2. Table 3 presents the inefficiency effects model, which examines the effect of the longevity and control variables on farm inefficiency. Two versions of the model are estimated; model 1 considers longevity in terms of the average productive life in the herd, and model 2 considers longevity in terms of the average age of culling in the herd. The 2 indicators of longevity are related by construction. To avoid the use of these seemingly related variables in the same model, we opted to estimate 2 different models that incorporate these variables separately. Model 1 and model 2 categorizations, presented in Tables 2 and 3 reflect this scenario.

The estimated production function models predict an average efficiency of 89% for the dairy farms under consideration. This means that on average, the farms could increase their production output by 11% at their current levels of production input variables if all farms were as efficient as the most efficient farms in the sample. Appendix Table A1 presents summary statistics of the efficiency scores for both model 1 and model 2. As is evident from Appendix Table A1, the efficiency scores are very similar across groups. Appendix Figure A1 presents a histogram of the efficiency distribution for model 1.

In the inefficiency effects model (Table 3), the 2 key variables of interest are those that capture herd average cow longevity (herd average productive life in model 1 and herd average age of culling in model 2). To incorporate for possible nonlinearity in the effect of longevity variables on inefficiency, we also incorporated squared values of the longevity variables in the models. However, model 2 rejected such nonlinearity and only the age of culling indicator is used to capture longevity. It is worth noting that the production function model and the inefficiency effects model presented in Table 2 and Table 3 are estimated in a one-stage approach but presented in separate tables for convenience. It should also be noted that in the inefficiency effects model, the dependent variable is the inefficiency score and, therefore, a negative coefficient for a given variable means a negative effect on the inefficiency and thus a positive effect on the efficiency and vice versa.

A longer herd average productive life was negatively associated with inefficiency in the linear indicator and positively associated with inefficiency in the squared indicator (Table 3). This suggests a U-shaped effect of the herd average productive life on inefficiency or an inverted U-shape effect on efficiency. Thus, inefficiency decreases with herd average productive life in the early phases and then increases with increased herd average productive life. This result is consistent with the graphic description of the relation between efficiency and productive life given in Appendix Figure A2. Model 2 predicts a positive relation between herd average age of culling and inefficiency, indicating increased inefficiency with increasing average herd age at culling (Table 3). Despite the model rejecting the inclusion of a nonlinear relation, graphic illustration of the relation between efficiency and herd average age of culling suggests an inverted U-shaped relation (see Appendix Figure A3).

Table 2. Production function estimation (estimates for inefficiency effects are given in Table 3)[1]

	Model 1			Model 2		
Frontier/production function	Output	SE	*P*-value	Output	SE	*P*-value
X_1: Variable cost	−0.30	0.37	0.41	−0.29	0.37	0.43
X_2: Fixed cost	0.87***	0.25	0.001	0.90***	0.25	<0.001
X_3: Asset	−0.37	0.29	0.20	−0.40	0.29	0.17
X_4: Labor hours	−0.29	0.31	0.36	−0.27	0.31	0.38
X_5: Land	1.30***	0.29	<0.001	1.29***	0.29	<0.001
$X_1 \times X_1$	0.14***	0.05	0.003	0.14***	0.05	0.004
$X_2 \times X_2$	0.06***	0.02	<0.001	0.06***	0.02	<0.001
$X_3 \times X_3$	0.05**	0.02	0.02	0.05**	0.02	0.03
$X_4 \times X_4$	0.02	0.03	0.60	0.02	0.03	0.54
$X_5 \times X_5$	0.04	0.04	0.30	0.04	0.04	0.32
$X_1 \times X_2$	−0.06***	0.02	0.004	−0.07***	0.02	0.003
$X_1 \times X_3$	0.03	0.03	0.33	0.03	0.03	0.24
$X_1 \times X_4$	0.02	0.03	0.57	0.02	0.03	0.56
$X_1 \times X_5$	−0.16***	0.03	<0.001	−0.16***	0.03	<0.001
$X_2 \times X_3$	−0.07***	0.02	<0.001	−0.07***	0.02	<0.001
$X_2 \times X_4$	0.02	0.02	0.33	0.02	0.02	0.38
$X_2 \times X_5$	0.04*	0.02	0.07	0.04*	0.02	0.07
$X_3 \times X_4$	−0.00	0.02	0.89	−0.00	0.02	0.84
$X_3 \times X_5$	0.05*	0.03	0.08	0.05*	0.03	0.09
$X_4 \times X_5$	−0.05	0.03	0.11	−0.05	0.03	0.12
t	0.13**	0.05	0.02	0.13**	0.05	0.02
$t \times t$	−0.00	0.00	0.17	−0.00	0.00	0.17
$t \times X_1$	−0.00	0.01	0.79	−0.00	0.01	0.86
$t \times X_2$	0.00	0.00	0.24	0.00	0.00	0.23
$t \times X_3$	−0.01***	0.00	0.004	−0.01***	0.00	0.004
$t \times X_4$	−0.01	0.00	0.13	−0.01	0.00	0.10
$t \times X_5$	0.02***	0.00	<0.001	0.02***	0.00	<0.001
Constant	5.02***	1.91	0.009	4.94***	1.92	0.01

[1]Model 1 considers longevity in terms of the average productive life in the herd, and model 2 considers longevity in terms of the average age of culling in the herd. t refers to year.

*$P < 0.10$; **$P < 0.05$; ***$P < 0.01$.

Our results also indicate that other variables have interesting associations with the technical inefficiency as a measure of economic performance (Table 3). For example, the subsidy and calving interval variables were found to increase inefficiency or decrease efficiency. The number of cows, which measures farm size, was found to reduce inefficiency, indicating that larger farms are associated with higher levels of technical efficiency. We also found that organic farms, compared with conventional farms, were more efficient, even though the results are not statistically robust across the 2 models. Compared with farms with automatic milking systems, farms with rotary milking or tiestall milking systems were less efficient. Breed was also significantly associated with farm efficiency. Farms using mainly Swedish Holstein dairy cows or a mix of Swedish Red and Holstein were more efficient compared with farms using mainly (>80%) the Swedish Red breed. Notably, housing system were not significantly associated with farm efficiency in our analysis. The McFadden's pseudo R^2 estimates for models 1 and 2, as shown in Tables 2 and 3, were very good (McFadden, 1977), suggesting that the selected models are fit. McFadden (1977) indicated that models with pseudo R^2 ranging from 0.2 to 0.4 have a very good model fit.

Farm Profitability, Productivity, and Longevity

Table 4 presents the results of the association between herd average cow longevity and farm economic performance measured by profitability (here measured as the gross margin). We estimated the effects of the 2 measures of herd average cow longevity in 2 separate models; we refer to these as model 1 and model 2 in Table 4. We found that productive life of the herd in our case has a significantly inverted U-shape relation with farm profitability ($P < 0.001$). This suggests that productive life has a positive relation with profitability at the initial stages followed by a negative relation in the later stages of the productive life. The same relation exists between profitability and herd average age at culling (model 2; Table 4). Moreover, some of the control variables have also showed a significant relationship with farm profitability. Milk yield as a measure of productivity, subsidy, and farm size (measured by number of cows) was found to have a positive and

Table 3. Inefficiency effects model, continued (estimated as part of the frontier model, separated for presentation convenience), herd-level averages were used in the model[1]

Inefficiency model	Model 1			Model 2		
	Inefficiency	SE	P-value	Inefficiency	SE	P-value
Productive life (d, log)	−15.73**	7.45	0.04	—	—	
Productive life (log^2)	1.15**	0.54	0.03	—	—	
Age at culling	—	—		1.12***	0.39	0.004
Subsidy (logged)	1.50***	0.13	<0.001	1.51***	0.13	<0.001
Number of cows	−0.03***	0.00	<0.001	−0.03***	0.00	<0.001
Calving interval	0.08*	0.04	0.06	0.05	0.04	0.26
Production type						
Conventional	Referent					
Organic	−0.24	0.15	0.11	−0.29*	0.15	0.06
Milking system						
AMS	Referent					
Milking parlor/rotary	0.26	0.17	0.14	0.26	0.17	0.13
Milking: tiestall	0.35	0.23	0.12	0.31	0.23	0.17
Breeds[2]						
SR (≥80%)	Referent					
SH (≥80%)	−0.33*	0.17	0.06	−0.28*	0.17	0.10
SR + SH (≥50%)	−0.37***	0.14	0.009	−0.34**	0.14	0.02
Other breeds	0.45***	0.17	0.009	0.47***	0.17	0.007
Housing system[3]						
Freestall, noninsulated	Referent					
Freestall, insulated	0.15	0.21	0.47	0.15	0.21	0.49
Tiestall	−0.03	0.23	0.90	−0.03	0.24	0.89
Year fixed effect	Yes, year fixed effects			Yes, year fixed effects		
Intercept	30.68	25.7	0.23	−31.42***	3.50	<0.001
N	1,958			1,959		
Pseudo R^2	0.35			0.28		

[1]Model 1 considers longevity in terms of the average productive life in the herd, and model 2 considers longevity in terms of the average age of culling in the herd. AMS = automatic milking system. Pseudo R^2 is an estimate of model fit.

[2]SR = Swedish Red; SH = Swedish Holstein; the proportion of each category in the total sample is given in parentheses.

[3]Barn-type reference category: loose housing, noninsulated.

*$P < 0.10$, **$P < 0.05$, ***$P < 0.01$.

significant relationship with profitability ($P < 0.001$ for all variables). Compared with farms with automatic milk systems, farms with rotary milking or tiestall milking systems were found to be less profitable in terms of gross margins.

Results from the estimation of the association between herd average cow longevity and farm productivity measured by milk yield are presented in Table 5. Again, 2 models were estimated to account for the different indicators for longevity. We found in our data that both the productive life of the herd and the age of culling of the herd exhibit a significant inverted U-shape relation with farm productivity. This indicates that herd average longevity indicators have positive relations with the productivity at the initial stages followed by negative relations in the later stages. Among the control variables, calving interval was found to have a significant negative association with productivity, indicating that longer calving intervals reduce the milk yield. Organic farms were found to be less productive in terms of milk yield compared with conventional farms. The herds with mainly Swedish Holstein cows or combinations of Swedish Red and Swedish Holstein cows were more productive in terms of milk yield than those with dominantly Swedish Red cows. As indicated by the F-statistics in Tables 4 and 5, overall, the models are significant. In addition, more than 50% of the variations in the gross margin and productivity (milk yield) are explained by the variables of interest and the other control variables.

Synthesis of Results

To synthesize our results, we found that herd average cow longevity as measured by average herd productive life and herd average age at culling, has an inverted U-shape relation with the farm economic performance measures of efficiency, profitability, and productivity. However, the point where the maximum performance is attained along the longevity measures varies across the performance measures (see Appendix Figures A2, A3, A4, A5, A6, and A7 for the graphic presentation of performance against longevity measures). Among the control variables, the subsidy variable is found to be

Table 4. Econometric estimation for pooled ordinary least squares regression and the effect of herd average longevity on gross margin[1]

Dependent variable: gross margin (log)	Model 1			Model 2		
	Gross margin	SE	*P*-value	Gross margin	SE	*P*-value
Productive life (d, log)	12.19***	4.58	0.008	—	—	—
Productive life (d, $\log^2$)	−0.88***	0.33	0.008	—	—	—
Age at culling (d, log)	—	—	—	26.42**	12.19	0.03
Age at culling (d, $\log^2$)	—	—	—	−1.76**	0.81	0.03
Milk yield	0.00***	0.00	<0.001	0.00***	0.00	<0.001
Subsidy (logged)	0.25***	0.06	<0.001	0.25***	0.07	<0.001
Number of cows	0.00***	0.00	<0.001	0.00***	0.00	<0.001
Calving interval	−0.01	0.03	0.86	−0.01	0.03	0.88
Production system						
Conventional	Referent					
Organic farm	0.17*	0.10	0.10	0.16	0.10	0.11
Milking system						
AMS	Referent					
Milking parlor/rotary	−0.18**	0.09	0.04	−0.18**	0.09	0.04
Tiestall milking	−0.53***	0.13	<0.001	−0.53***	0.13	<0.001
Herd breed						
SR (≥80%)	Referent					
SH (≥80%)	0.13	0.11	0.24	0.14	0.11	0.22
SR + SH (≥50%)	0.10	0.10	0.33	0.10	0.10	0.31
Other breeds	−0.07	0.12	0.58	−0.06	0.12	0.61
Housing system						
Freestall, noninsulated	Referent					
Freestall, insulated	0.10	0.13	0.45	0.10	0.13	0.43
Tiestall	−0.02	0.15	0.90	−0.02	0.15	0.91
Year fixed effect	Yes, year fixed effects			Yes, year fixed effects		
constant	−34.19**	15.91	0.03	−91.37**	46.09	0.05
N	1,730			1,730		
F-statistic	32.48***			32.40***		
R^2	0.55			0.56		

[1]Model 1 considers longevity in terms of the average productive life in the herd, and model 2 considers longevity in terms of the average age of culling in the herd. Robust standard errors clustered at farm level. The dependent variable is log (gross margin). Milking system reference category: automatic milking system. Breed reference category: Swedish Red (SR) breed more than 80% of the herd. SH: Swedish Holstein. Barn type reference category: loose housing.

*$P < 0.10$, **$P < 0.05$, ***$P < 0.01$.

negatively related to efficiency and positively related to profitability, with no significant relation to productivity.

Furthermore, farm size measured by the number of cows was found positively associated with efficiency and profitability but had no significant relationship with productivity in terms of milk yield. We did not find a strong relationship for efficiency and profitability measures for the calving interval variable, whereas it was found to exhibit a strong negative relation with productivity in terms of milk yield. Herd breed was significantly associated with productivity and efficiency; herds with mainly Swedish Holstein or mainly Swedish Red and Swedish Holstein cows were more productive and efficient compared with herds with mainly Swedish Red cows.

DISCUSSION

This study focused on the associations between the herd average longevity of dairy cows and farm economic outcome, where we used 2 indicators of dairy cow longevity on herd level and 3 indicators of economic outcome. A herd-level merge of detailed economic data (FAS data) and detailed NHRS data resulted in a unique data set that enabled the analysis. The paper contributes to existing literature by detailing how the herd average longevity indicators are associated with farm economic outcomes and adds to the understanding about how strategies regarding average herd longevity of dairy cows can be associated with economic sustainability of dairy farms.

It should be noted that although FAS is the most comprehensive data set for farm efficiency estimations in Europe, it consists mainly of accounting data. This means that production factors and production outputs derived from FAS data can mainly be measured in monetary units (except for labor and land in our empirical model specification). We acknowledge the limitations that follows from this; that the resulting technical efficiency scores are not only estimated from a quantity correspondence of production factors and outputs but

Table 5. Effect of herd average longevity on milk yield (log)[1]

	Model 1			Model 2		
Variable	Milk yield	SE	*P*-value	Milk yield	SE	*P*-value
Productive life (d, log)	2.34***	0.60	<0.001	—	—	
Productive life (log^2)	−0.18***	0.04	<0.001	—	—	
Age at culling (d, log)	—	—		6.39***	2.12	0.003
Age at culling (log^2 of age of culling, squared)	—	—		−0.44***	0.14	0.002
Subsidy (logged)	−0.01	0.01	0.67	−0.00	0.01	0.73
Number of cows	0.00	0.00	0.99	−0.00	0.00	0.92
Calving interval	−0.03***	0.01	<0.001	−0.02***	0.00	<0.001
Production type						
Conventional	Referent					
Organic farm	−0.11***	0.02	<0.001	−0.11***	0.02	<0.001
Milking system						
AMS	Referent					
Milking parlor/rotary	0.01	0.02	0.55	0.01	0.02	0.56
Tiestall	−0.04*	0.02	0.07	−0.04*	0.02	0.06
Herd breed						
SR (SR ≥ 80%)	Referent					
SH (SH ≥ 80%)	0.08***	0.02	<0.001	0.08***	0.02	<0.001
SR + SH (≥50%)	0.03*	0.02	0.05	0.03*	0.02	0.06
Other breeds	−0.03	0.03	0.25	−0.03	0.03	0.24
Housing system						
Freestall, noninsulated	Referent					
Freestall, insulated	−0.02	0.02	0.34	−0.02	0.02	0.37
Tiestall	0.01	0.03	0.82	0.01	0.02	0.74
Year fixed effect	Yes, year fixed effects			Yes, year fixed effects		
Constant	1.79	2.09	0.39	−13.84*	8.04	0.09
N	1,958			1,958		
F-statistic	10.39**			12.14***		
R^2	0.52			0. 62		

[1]Robust standard errors clustered at farm level. The dependent variable is log (milk yield). Milking system reference category: automatic milking system (AMS). Breed reference category: Swedish Red (SR) breed more than 80% of the herd. SH: Swedish Holstein. Barn type reference category: loose housing.

*$P < 0.10$, **$P < 0.05$, ***$P < 0.01$.

also from variables that are compiled based on prices. Still, we consider the technical efficiency scores measured here valid and interesting economic indicators of the farms, because they are derived from a simultaneous consideration of all considered production factors and the production outputs.

It should also be noted that the average herd longevity indicators do not consider the distribution of longevity across the herd; this means that farms with a wider distribution of cow longevity may have the same average herd longevity as a farm with a more narrow distribution of longevity, although they are likely to exhibit different strategies regarding voluntary culling of dairy cows. This should be kept in mind when interpreting the results. Future research will have an important task in considering the effect of the distribution of longevity across herds on the economic indicators to more fully understand this complexity.

The regression results point toward an overall positive relationship between the economic and longevity indicators, as well a nonlinear relationship between those variables, where economic performance is first increasing with herd average longevity and then decreasing. An important question is when this change happens. Our descriptive results indicate that it happens around a herd average cow productive life of 950 to 1,000 d (about 31.1 to 32.8 mo) or at a herd average cow total age of about 1,700 d (55.7 mo) for technical efficiency and gross margin, and at a herd average cow productive life of 800 d (26.2 mo) or at a herd average cow total age of around 1,600 d (52.5 mo) for milk yield (see Appendix Figures A2, A3, A4, and A5). Assuming an average lactation of 10.5 mo for Swedish dairy cows (Juverportalen, 2023), and a dry period of about 2 mo, these figures indicate that the turning point happens at a herd average of 2.5 to 2.6 lactations per cow (assuming no dry period after the last lactation) for the technical efficiency and gross margin, and at a herd average of 2.1 lactations per cow for milk yield (assuming no dry period after the last lactation). The results for technical efficiency and gross margin correspond well with the herd average number of lactations (2.6) a Swedish dairy cow is kept for production (Växa Sverige, 2021b), whereas the results for gross margin indicate a lower herd average number of lactations. The observed differences between the types of economic indicators are interesting. Yield, as compared with technical efficiency and gross margin, is likely more easily observed and understood by individual farmers. Still, our results indicate it would be beneficial for the farmers, from a technical efficiency and gross margin point of view, to keep the animals longer than what is indicated by the yield, and thus, allow for longer average herd longevity. Those economic indicators include both revenues and costs, and therefore represent a more comprehensive assessment of the economic situation. As indicated, we base the discussion about the economically optimal average herd longevity on our descriptive results. Future research has an important task in further developing the models describing the relationships between economic performance indicators and longevity indicators so the models can be used to simulate more exact estimations at the point where the optimal average herd longevity happens; this model development was beyond the scope of the current paper.

Compared with other countries with cows of high genetic merit, longevity in Swedish dairy cows is lower (Schuster et al., 2020), and explanations for this can only be speculative. Dutch farmers have strict environmental regulations that make it beneficial to have fewer animals on the farm. One way to achieve fewer animals on the farm is to keep the recruitment stock at a minimum; this minimizes the heifer push (Bergeå et al., 2016) and therefore, results in a higher longevity. Genomic testing has partly influenced the increase in cow longevity in the United States. Genomic testing also occurs in Sweden, but the phenotypic results in length of productive life may show some time lag before it is observable on herd level. The age distribution in the herd may affect the results, because herds with a short longevity have a larger share of first-lactation cows. Because older cows in general have higher milk yield than first-lactation cows (Langford and Stott, 2012), a high proportion of first-parity cows in the herd will hold back milk yield, while a high proportion of parity 2 and 3 cows would give a higher total milk production on the farm. However, in parity 3, cell counts typically increase, and the risk of several production diseases also increases. It is likely that these factors affect decisions on farm level in Sweden, taking into account the restricted use of antibiotics.

From a methods perspective, it should be noted that our results are based on observational, rather than on experimental data, and as such, they should be taken to represent the relationship between economic indicators and the dairy herd longevity indicators that exist empirically in our sample. Notably, this means that our results reflect the practices in the setting where data were collected. We used control variables to account for aspects that may affect the economic indicators along with the indicators of herd longevity. This means that we can interpret our results as highlighting the relationships between the economic and longevity indicators, while controlling for those other factors that may also affect this relationship. Nevertheless, gaining further insights into how herd longevity affects the farm economic outcome, future experimental (rather than observational) data may have an important role in investigating this question in a more controlled setting, in particular when investigating the potential of increased dairy herd longevity beyond the current practice in our sample. Having said that, a key advantage of our approach is that the data reflects decisions made in practical dairy farming. Therefore, we recommend a future experimental approach to collect data from dairy farms where strategies to work with longer average herd longevity are randomly distributed across the participating farms in a controlled manner. Such a transdisciplinary research approach would shed more light on the possible limits of the economic impact of enhanced dairy cow longevity. In addition, now that our study can conclude that, at least in our sample, average herd longevity is significantly related to the economic indicators and that the relationship is inverted U-shaped, future research will have an important task in developing and testing a theoretical framework to detail the causal links between average herd longevity and economic indicators.

Our control variables point to additional factors that significantly influence the dependent variables. As such, the control variables provide information about possible economic impact beyond the longevity indicators studied in this paper. We also found that the level of subsidy is negatively related to technical efficiency. This is consistent with results by Latruffe et al. (2016) who found a relationship between technical efficiency and subsidy. We also found that the level of subsidy is positively related to profitability and has no significant relation to productivity. The herd size (number of cows) is positively associated with technical efficiency, similar to results by Dong et al. (2016), and with the gross margin but has no significant relationship with average milk yield per cow. The calving interval was found to have a negative relationship with technical efficiency, similar to results by Pérez-Méndez et al. (2020), and with average milk yield per cow, but there was no significant relationship with the gross margin. Our control variables are admittedly at an over-arching level. Future research could benefit from including more detailed dairy cow related control variables (e.g., more details about feeding). Future research could also investigate the role of farmers' managerial ability in explaining both the average herd longevity and the economic indicators considered here; admittedly, ability is a factor that may determine both of those variables but was not possible to control directly for in our longitudinal register dataset, but is captured indirectly from our fixed effects model specifications.

In addition, it should also be noted that our focus is on the relationship between economic indicators and longevity indicators. Still, the question of what determines longevity in itself is an interesting focus for future research. In particular, further research is needed to better understand the driving forces behind voluntary culling decisions, especially those of attitudinal type. This type of research is emerging (Rilanto et al., 2022) and adds interesting behavioral insights into farmers' culling decisions. Future research could focus on farmers' attitudes, perceptions and trade-offs with respect to voluntary culling. Our findings also point to a need for the studied dairy sector to take the gross margin and technical efficiency into consideration in culling decisions. Notably, it is well known that the maximum yield may not coincide with the maximum economic returns. Our results point to the need for a more careful discussion about economic indicators and how they are related to each other. In particular, average yield per cow may be too simplistic, as it does not consider the resources needed to increase yield, and thus the cost of increasing yield may be neglected. The technical efficiency and gross margin indicators take the need for resources into explicit consideration and are therefore more useful for economic decision-making.

Our results are interesting when considering prospects for achieving more sustainable dairy production. Previous research has highlighted that increased longevity is associated with lower levels of methane per kilogram of milk (Grandl et al., 2016, 2019). Furthermore, when cows are kept longer in production, the emissions caused by rearing a calf to a pregnant heifer can be allocated over a larger volume of total milk production from the cow, improving the overall environmental sustainability of dairy production (von Soosten et al., 2020). Keeping the cows for more lactations may also improve the social sustainability of dairy production, because short longevity signals that the cows are kept in such a way that they cannot function over an extended period of time (Röcklinsberg et al., 2016). Adding these insights to our results highlights that with current practices in Swedish dairy production, there may be a tradeoff between enhancing environmental and social sustainability and economic sustainability. Understanding how longevity can be increased in a way that is economically favorable is therefore important to improve the overall sustainability of dairy production and needs to be addressed in future research.

CONCLUSIONS

This paper contributes to the scarce literature about how the longevity of dairy cows, at herd level, is related to the economic performance of farms. Our results can support on-farm decision-making about the replacement of dairy cows in the herd, thus improving the economic situation on farms. Based on our results, farmers and their advisors could consider a variety of economic indicators when discussing average herd longevity and how it might be associated with the farm economic outcomes. Farmers and their advisors can also discuss strategies to deliberately arrive at a specific average herd longevity that fits the individual farm. Linking findings with previous knowledge about the climate consequences of keeping dairy cows for a longer period of time with insights about longevity for the social acceptance of dairy production suggests that keeping cows for a larger number of lactations than the current practice may imply trade-offs between sustainability dimensions. Future research has an important task in understanding how longevity can be improved in a way that is in line with overall sustainability.

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APPENDIX

Table A1. Summary of efficiency scores from model 1 and model 2

Model	Observations	Mean	SD	Minimum	Maximum
1	1,958	0.888	0.088	0.487	1.00
2	1,959	0.887	0.088	0.486	1.00

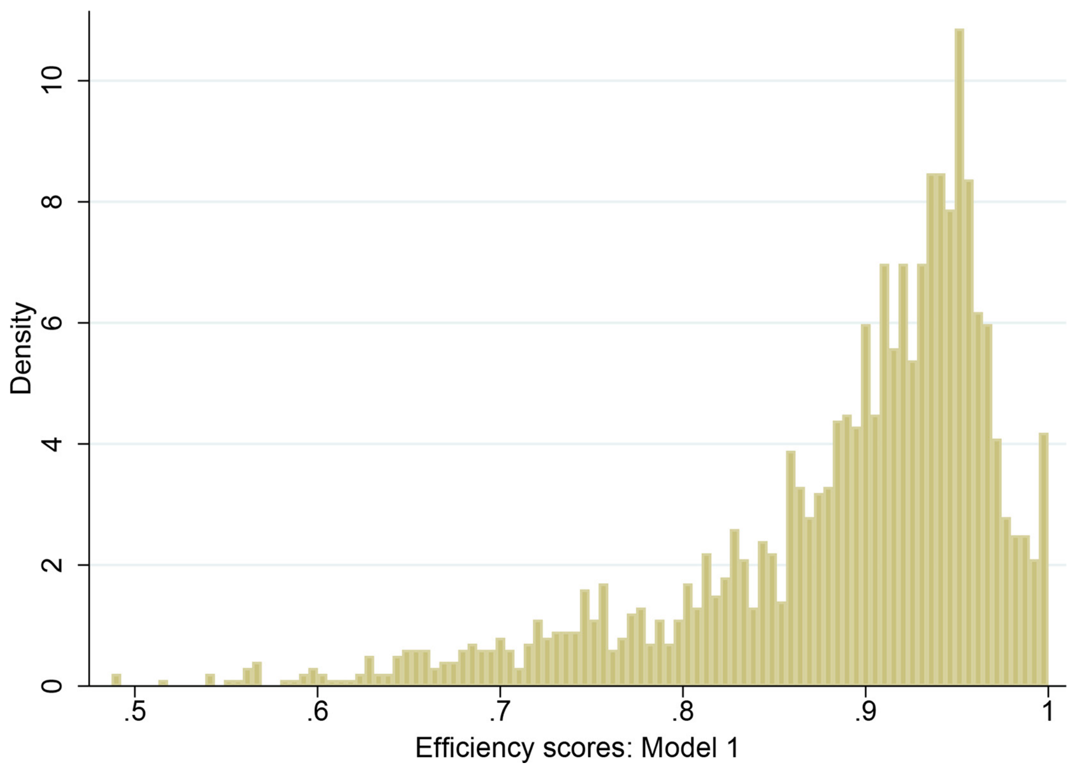

Figure A1. Histogram of efficiency scores from model 1, which considers longevity in terms of the average productive life in the herd.

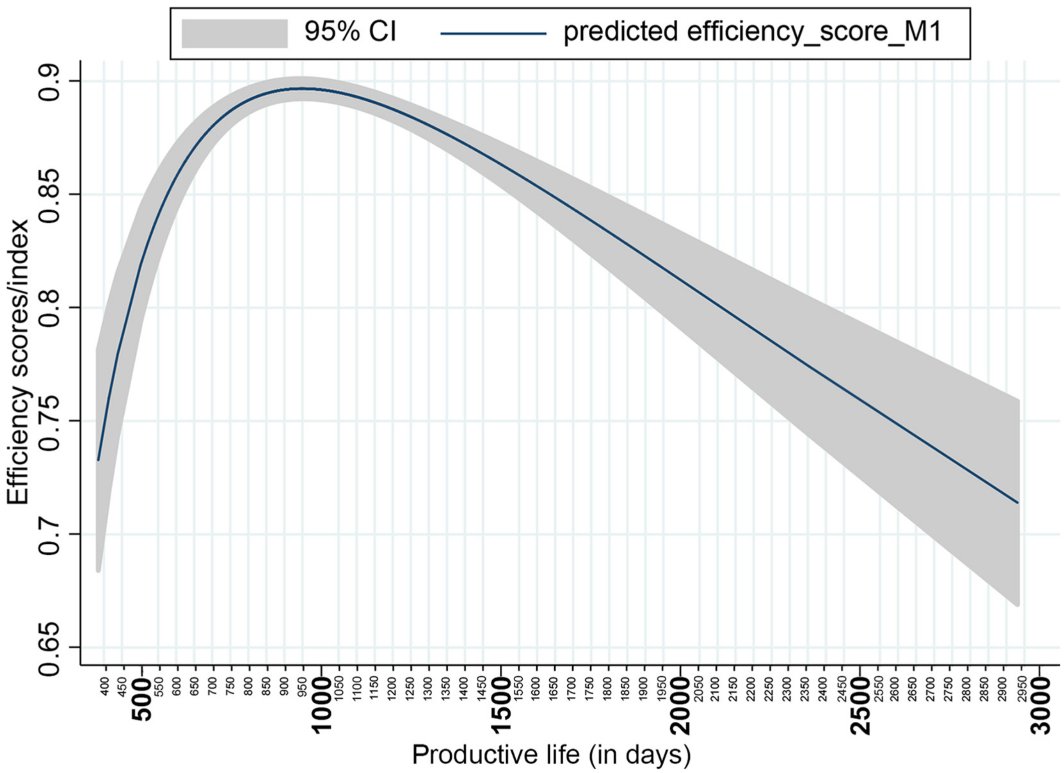

Figure A2. Graphic analysis of efficiency scores across herd average productive life for model 1 (M1).

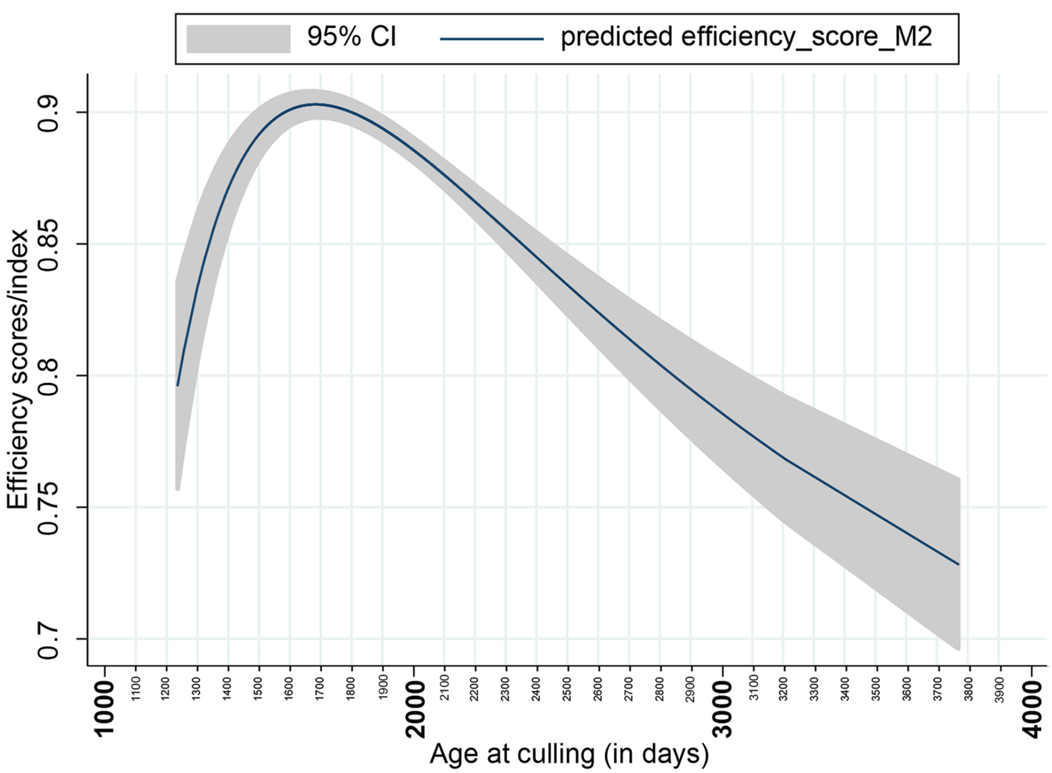

Figure A3. Graphic analysis of efficiency scores across average herd age at culling for model 2 (M2).

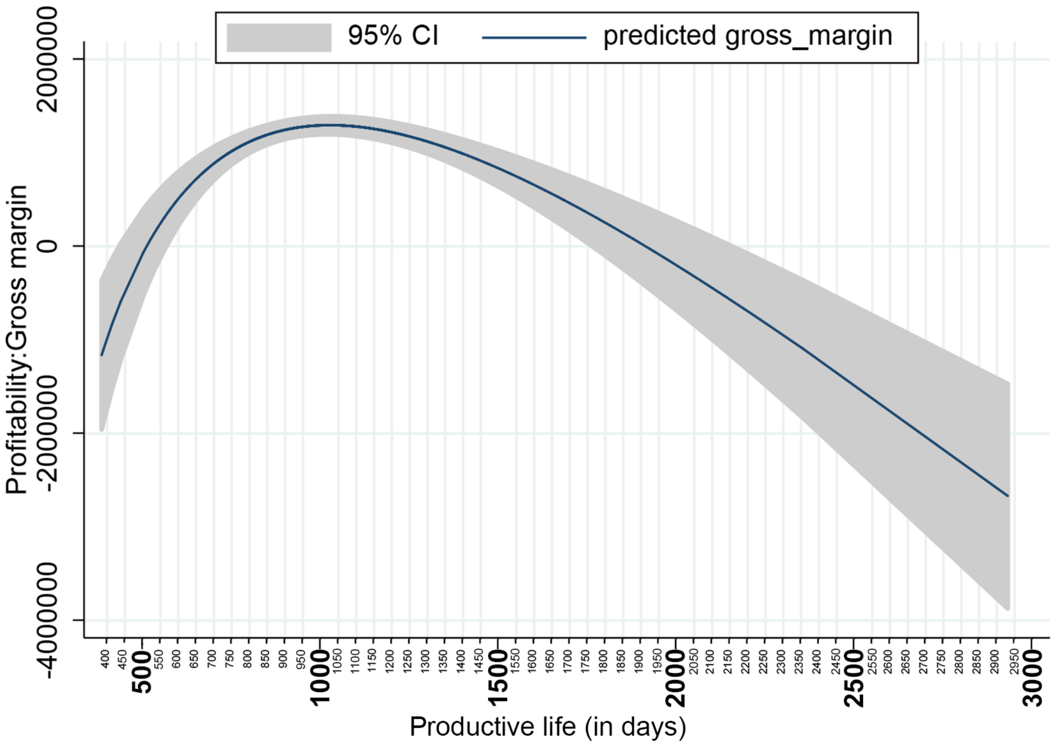

Figure A4. Graphic analysis of profitability (gross margin) across longevity (average herd productive life in days).

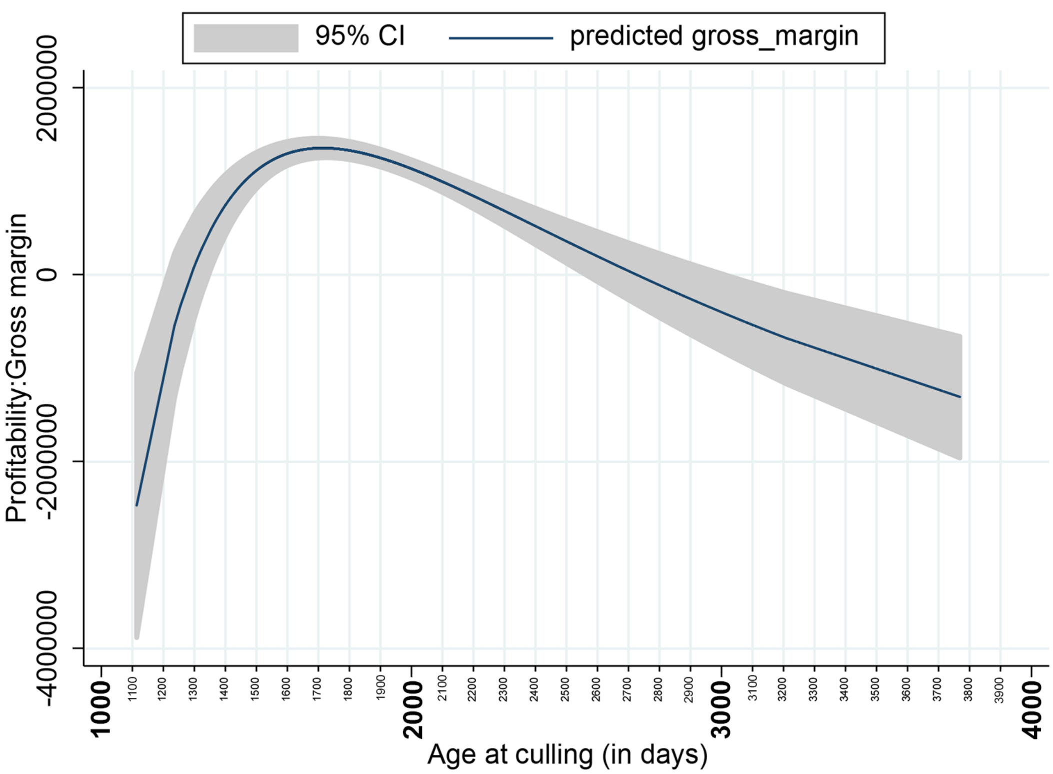

Figure A5. Graphic analysis of profitability (gross margin) across longevity (average herd age at culling in days).

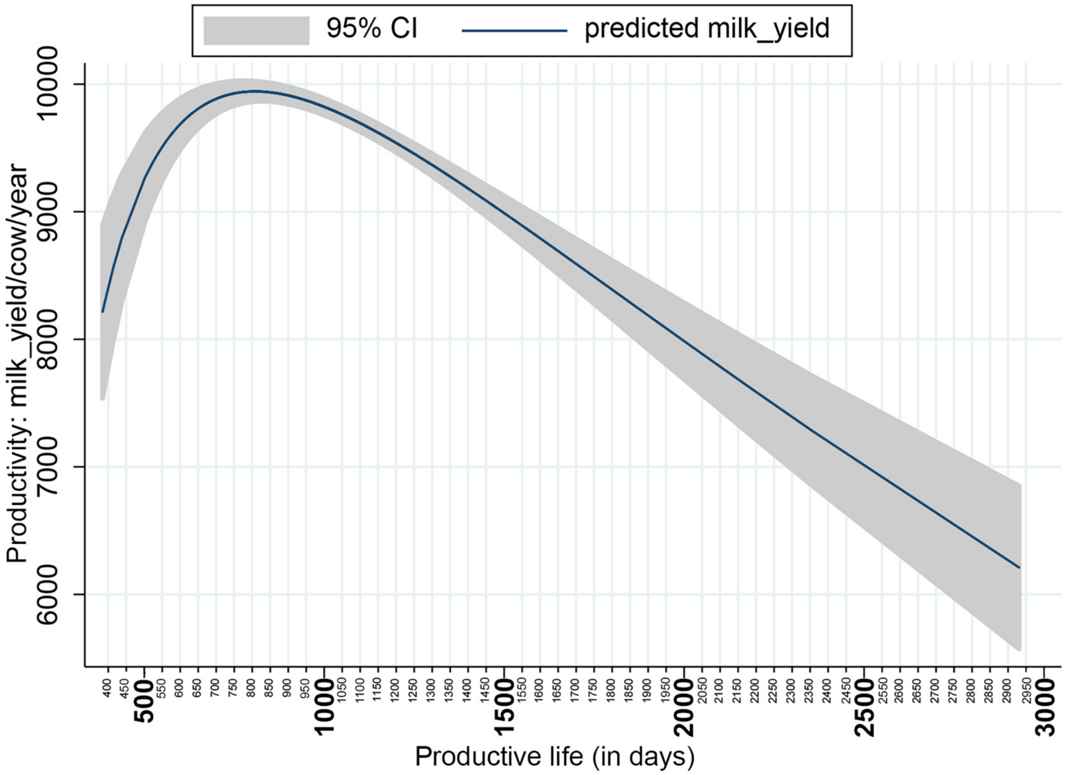

Figure A6. Graphic analysis of productivity (average milk yield/cow per year) across longevity (average herd productive life in days).

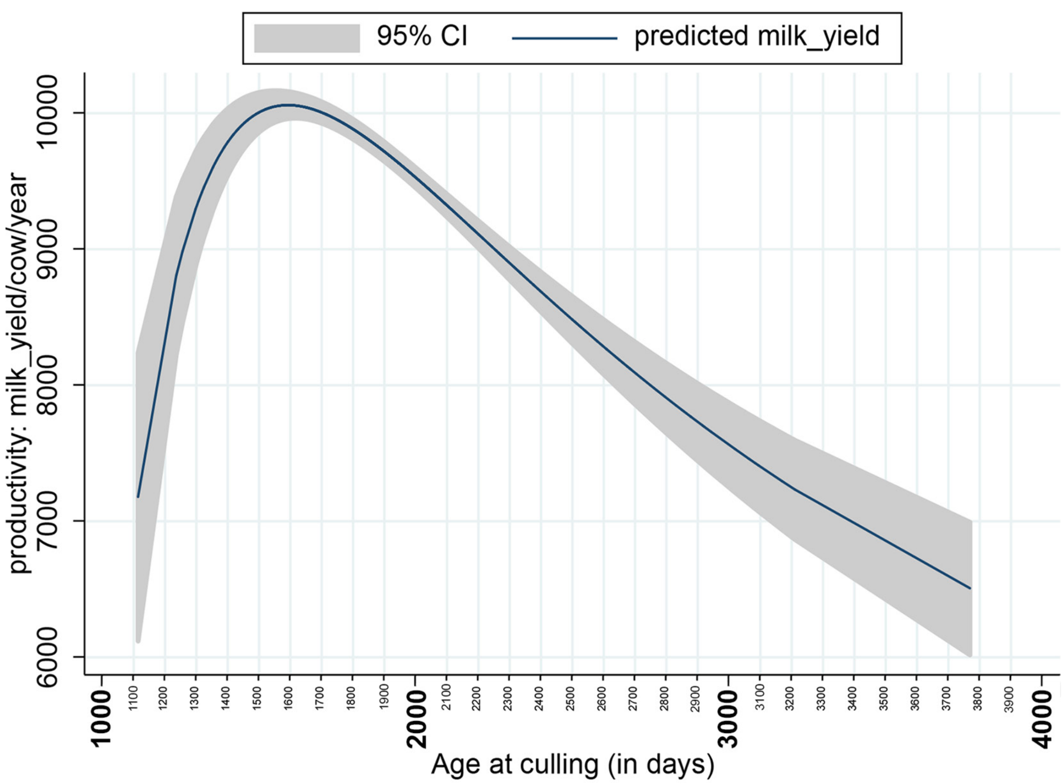

Figure A7. Graphic analysis of productivity (average milk yield/cow per year) across longevity (average herd age at culling in days).